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Research Note

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PROGRESS TOWARD LOCATING LIGHTNING FIRES

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ABSTRACT

Systems to enable land managers to locate, evaluate, and counter the fire threat of lightning storms are in the early stages of development. In the western U.S. and Alaska, the Bureau of Land Management has established networks of instruments that locate lightning strikes by means of recorded azimuths. Further research could add important capabilities: identifying and counting strikes with fire-starting potential, estimating ignition probabilities under various fuel and weather conditions, and predicting fire behavior immediately after ignition.

KEYWORDS: Lightning, lightning location, fire location, wildland fires, fire planning

Statistics from the Division of Cooperative Fire Control show that each year, in the Western States, lightning starts about 44 percent of the approximately 20,000 fires that occur. Lightning also accounts for about 60 percent of the million or so acres burned on private, State, and Federal lands. For Regions 1 and 3 of the USDA Forest Service, these percentages are significantly higher. Although lightning fires are relatively rare and unimportant in the eastern half of the Nation, southeastern forests have been shown to be more susceptible to insect attacks as a result of lightning damage to trees (Taylor 1977).

New trends in fire management require fresh approaches to fire suppression. Contrary to what one might expect, allowing some fires to burn for ecological reasons calls for more, not less, fire management activities than employed in the past. At the same time, the costs are climbing and funds are limited. For these reasons, fire managers need new technology that will reduce costs.

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A new lightning locating device offers considerable promise for improving management and reducing costs. The device locates cloud-to-ground lightning strokes (Noggle and others 1976). A six-station network now covers Alaska. Another is being set up to cover the Great Basin region. Both of these lightning direction-finding networks are sponsored by the U.S. Department of Interior, Bureau of Land Management.

The Great Basin network consists of 12 stations, each having a device that measures the azimuth to lightning. The azimuths are combined at several central stations to compute lightning storm locations, which will then be sent to fire control organizations. Unfortunately, this network will have severe limitations because presently we have no means to assess the output in terms of fire behavior or to use the output in pre-suppression and suppression operations. The purpose of this paper is to describe efforts toward developing a system that will assist fire managers not only to locate lightning storms but also to predict how many fires are likely to start and how fast they will burn.

For many years, fire suppression organizations have relied on intelligent adaptive computers--lookouts--to locate lightning and detect fires. Lookouts can observe lightning discharges and storm locations, and subsequently monitor strike locations for the appearance of fire. Lookouts can also keep track of many of the variables influencing the fire growth process, and make decisions based on this input. Since their inception, lookouts have detected nearly half of all lightning fires in Region 1 (Barrows 1951, 1977[2]).

The effectiveness of the lookout is demonstrated in figure 1. Here we show lightning-fire detection times for four forests in Region 1, comparing lookouts, pilots, and others, including road patrols and airborne infrared scanners. This figure illustrates that, within 5 hours, lookouts catch almost three-fourths of all fires that grow into class B or larger. On the other hand, pilots take almost 20 hours to accomplish the same task.

Detection times differ because lookouts know where to look for potential lightning-fires. Decreasing aircraft detection time to that of lookouts could reduce burned acreage and effect more efficient use of aircraft and firefighters. However, past attempts to substantiate this possibility have been unsuccessful.

In the absence of a locating and timing system, detection time cannot be accurately established. With few exceptions, detection times appearing on Forest Service Form 5100-29 are, at best, educated guesses by airborne observers and others. Therefore, it is impossible to use their data (fig. 1) as baselines from which to measure the effectiveness of a location system. A location system is thus necessary to establish the usefulness of a location system. We can, however, speculate that a decrease in detection time would reduce fire size.

We were able to examine the probabilities of fire growth in available statistics (data from Region 1, western forests, 1946-1973). The following gives the escape probability by fire class:

Fire size	A	B	C	D
Probability of fire becoming larger	0.15	0.11	0.25	0.58

[2]Lightning fires in Northern Rocky Mountain Forests. Final Rep., Contract 16-440-CA. Intermt. For. and Range Exp. Stn., Missoula, Mont.

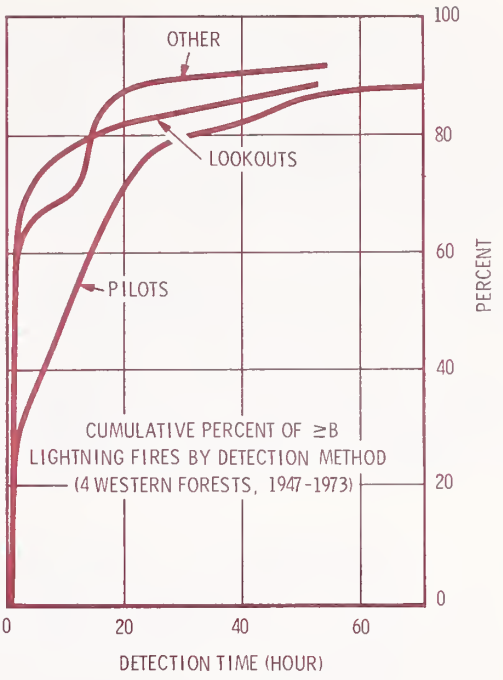

Figure 1.--Cumulative probability for detection time as reported on Forest Service form 5100-29 for four forests in Region 1.

Simply put, the probabilities are as follows: If a fire is presently class C, for example, the odds are 1 in 4 that it will grow to be a class D or larger fire; 25 percent of class C fires get away. From these probabilities, we see that about 2 percent of all lightning fires become larger than class B. If these odds could be reduced, a definite cost savings would result, and there is a good chance that a properly developed lightning locating system would accomplish this. Earlier detection, resulting from knowing where to look, should speed overall response time. This in turn would decrease the chance of escape to the potentially disastrous class C size.

Forest Service fire management personnel have recently called for a thorough overhaul of fire planning and are presently developing a new fire planning guide to replace the 1972 version. In the existing version, the basis for scheduling air patrols is vague and the times of day for such patrols are fixed. A lightning locating system, properly applied, would enable these patrols to be made as needed. In addition, those storms that presently "sneak by" a sparse lookout network, as in wilderness areas, could be caught. A few years of data would provide a much better estimate of the number of airplane hours required. A fire plan incorporating a lightning locating system might also include, when fire danger is extreme, the use of aircraft with smokejumpers on board, or retardant-carrying aircraft vectored to the lightning locations without an actual fire having been reported.

Fires detected more than 1 day after ignition have traditionally been called "holdover" fires. Because part of a lightning locating system is data storage, a memory of past lightning strikes would help shorten detection time because observers will know where to look.

So far we have discussed only the suppression uses of a lightning locating system. What about other possibilities? Obviously, such a system would provide good data on detection times for evaluating responses of all types of detection methods. The raw data would also be beneficial for other research studies, such as establishing a lightning climatology, and also for updating the system itself. Applications in other areas of fire management are also possible.

Long range fire planning will benefit through use of combined location and fire data. Thunderstorm "alleys" can be identified and the probability of naturally-occurring fire can be better assessed, resulting in improved fuel treatment prescriptions. In addition, fire probability maps can be generated and used in forest models, aiding in long-range planning. These maps can also be used as inputs to FOCUS-like models for teaching and evaluating response to fire occurrence. All of this can be done because the lightning-fire locating system will respond to historical and simulated lightning scenarios, as well as real-time occurrences.

Having laid down some possible uses for a system to locate lightning fires, we should review design criteria and the research necessary. For operations and planning, we are interested in fires, not lightning. Therefore, a primary consideration is the relationship between lightning and fires. Figure 2 illustrates the chain of events leading to a "successful" or "reported" lightning fire. That portion of the figure within the dotted lines is hidden from observation because of the random nature of its occurrence. That is, if an observer happened to be on the spot, the phenomena could be seen quite clearly, but the chance of one being there is vanishingly small.

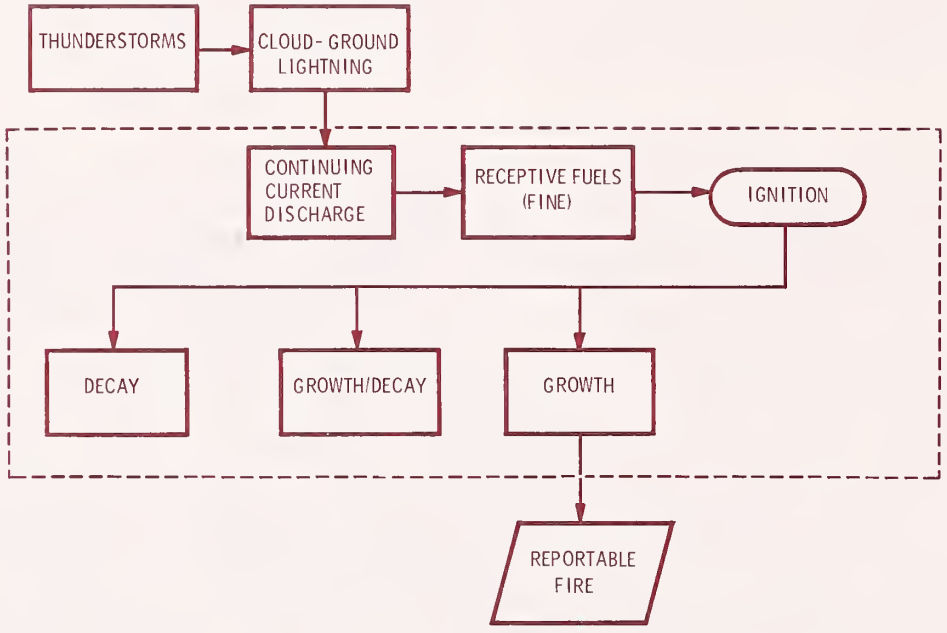

Figure 2.--Events involved in the generation of a lightning-fire. Those within dotted lines would be visible to an observer on the spot.

A lightning fire detection system includes a model for those hidden processes that lead to a reportable fire. There are two basic approaches to this model. One is to gather data on the variables involved and to produce a purely empirical model (Nickey 1976; Kourtz 1974). The other approach is to construct a purely physical model from first principles. Neither of these approaches is very efficient because of the large variances involved and the effect of random factors. A better approach is to combine the two into a semi-empirical form which allows for easy modification as data is obtained.

Some of the links for modeling the lightning fire chain of figure 1 have been forged, including characterizing lightning and the relationship between types of lightning strokes and ignition of fires. Fuquay (1972) demonstrated that by far the largest part of lightning fires can be linked to certain cloud-to-ground lightning strokes--those containing a continuing current. Most cloud-to-ground discharges can be considered similar to the spark generated by shuffling along a rug or the ignition spark in an automobile engine. The continuing current, on the other hand, is more like the arc from an arc welder. In the northern Rocky Mountains, approximately 20 percent of cloud-to-ground strokes are accompanied by arc-type discharges. Hence roughly 20 percent of the cloud-to-ground strokes are potential fire starters. Further, the probability that a cloud-to-ground flash will ignite forest fuels increases with the duration of the continuing current because total energy released is higher.

The system for locating lightning must differentiate between these likely fire starters and ordinary cloud-to-ground discharges. Furthermore, any model, whether based on physics or statistics, should use the energy released by the continuing current as a means of estimating fire ignition potential.

The next link to consider is the relationship between the continuing current and the on-the-ground conditions that determine *ignition* probability. The link is partially completed. A model for lightning fire ignition (Fuquay and others 1979) was developed for the National Fire-Danger Rating System (NFDRS). The model is a hybrid because it combines the physics of ignition with statistical variables dealing with continuing current energies and thunderstorm behavior. Although not specifically designed for real-time use, the model is readily adaptable for it.

The final link in the lightning fire chain is the growth of an ignition to a reportable fire. It is the modeling of this link that is the most intransigent and needs the most work at this time. A combination of laboratory and field investigations will be necessary to obtain data for developing a fire probability model.

What other criteria can we set for the system? We have to immediately provide information from the locating device and probability model to the land managers and store the data in an easily accessed fashion for future use. We must try to implement the system at the lowest cost and with the greatest flexibility. Therefore, extensive use of large computer facilities should be avoided. Short-term local storage will be necessary for locating holdover fires and possible insect-infested areas and for determining seasonal trends. Long-term local storage may also be dictated by fire planning needs. The form of display and storage is left as a task to be done.

The development of a lightning-fire locating system as outlined above started with the establishment of the lightning locating devices by the Bureau of Land Management. The remainder of the system is, as we discussed earlier, in various stages of construction.

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